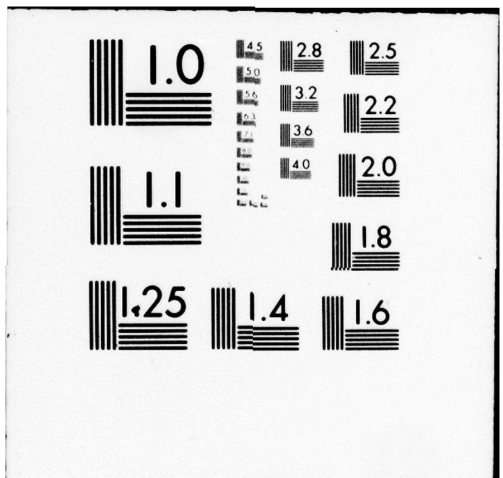
AD-A075 979 ARMY MISSILE COMMAND REDSTONE ARSENAL AL TECHNOLOGY LAB F/G 17/7
ACTIVE LASER SEEKER CONCEPTS EVALUATION.(U)
JUN 79 K SEYRAFI , T H JAMES
UNCLASSIFIED DRSMI-T-CR-79-22 NL

| OF |
AD
A075979

END
DATE
FILMED
11 -79
DDC



MICROCOPY RESOLUTION TEST CHART

AD A075979

DDC FILE COPY

TECHNICAL REPORT T-CR-79-22

12

LEVEL II

ACTIVE LASER SEEKER CONCEPTS EVALUATION

Khalil Seyrafi

Thomas H. James

Technology Laboratory

June 1979

U.S. ARMY MISSILE COMMAND

Redstone Arsenal, Alabama 35809

Approved for public release; distribution unlimited.

DISPOSITION INSTRUCTIONS

DESTROY THIS REPORT WHEN IT IS NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

DISCLAIMER

THE FINDINGS IN THIS REPORT ARE NOT TO BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION UNLESS SO DESIGNATED BY OTHER AUTHORIZED DOCUMENTS.

TRADE NAMES

USE OF TRADE NAMES OR MANUFACTURERS IN THIS REPORT DOES NOT CONSTITUTE AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL HARDWARE OR SOFTWARE.

1

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
T-CR-79-22

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
6 Active Laser Seeker Concepts Evaluation

5. 9 TYPE OF REPORT & PERIOD COVERED
Technical Report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 Khalil Seyrafi [redacted]
Thomas H. James

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Commander
US Army Missile Command
ATTN: DRSMI-TE (R&D)
Redstone Arsenal, Alabama 35809

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
12 44

11. CONTROLLING OFFICE NAME AND ADDRESS
Commander
US Army Missile Command
ATTN: DRSMI-TI (R&D)
Redstone Arsenal, Alabama 35809

12. REPORT DATE
11 Jun[redacted]979

13. NUMBER OF PAGES
41

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
14 DRSMI-T-CR-79-22

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Active and Passive Systems
Active Seeker
Active Laser System
Coherent Seeker

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This final report covers the subject of active search and acquisition by a 10.6 micrometer missile seeker. The primary issue is the discrimination capabilities of an active system. Included in this report are performance evaluations in coherent and incoherent modes, compared to passive seekers, evaluations of the viability of several target discriminants, considerations regarding acquisition scan techniques, and economic considerations of such active seeker designs.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

393 427

CONTENTS

ILLUSTRATIONS

Figure | Page

1. INTRODUCTION

This final report covers the subject of active search and acquisition by a 10.6 micrometer missile seeker. The primary issue is the discrimination capabilities of an active system. Included in this report are performance evaluations in coherent and incoherent modes, compared to passive seekers, evaluations of the viability of several target discriminants, considerations regarding acquisition scan techniques, and economic considerations of such active seeker designs.

For a number of years, it has been feasible to implement day-night air to ground missile seekers using either semi-active designator techniques, passive long-wave-length Infrared (IR) techniques or TV guidance methods. In all these systems, experience had shown that the target position must be clearly indicated to the seeker by means of an external designator, or by physically pointing the seeker boresight at the desired target, prior to acquisition. The problem in implementation of an acquisition after launch is providing the seeker with the intelligence to pick out the proper target by discriminating against several intentionally or unintentionally similar appearing objects.

Clearly, the major benefit of an active seeker is that of providing the needed discrimination capability. Generally, neither tracking performance nor acquisition range will be improved over passive seekers. The active seeker must therefore be considered as a trade-off between increased complexity and cost versus the added potential for acquisition after launch. To complete the picture, the utility of competing identification techniques, such as multi-color passive systems, needs to be compared with the active seeker system in terms of overall net cost and performance.

Based on the study, it was concluded that the use of an active coherent Continuous Wave (CW) missile seeker could permit target motion determination. Target-depth signature is another potential discrimination technique of value. To obtain the most benefit from an active system, a maximum likelihood ratio estimate based on a combination of discriminants will be the best approach. Some first-order cost estimates are presented for a coherent seeker for comparison with passive seekers. The question of overall cost effectiveness of an active seeker versus a passive seeker, however, cannot be answered at this time. Further studies and development effort are required to assess the potential performance gains and to establish realistic complexities and costs.

2. BASIC CONSIDERATIONS FOR ACTIVE AND PASSIVE SYSTEMS

The heart of the matter of active seeker utility is discrimination capability. Before this capability can be addressed, however, the relative performance and merits of differing active seeker types will be considered. The basic signal-to-noise issue of various seekers will be addressed first. Next, the issue of basic system configurations will be addressed.

A. SIGNAL TO NOISE CONSIDERATIONS

In this section, we will briefly review the performance of pulse versus CW coherent systems, pulse versus CW incoherent systems and for good measure, the performance of a purely passive sensor of similar aperture and resolution. It is shown that the coherent pulse system is superior to the coherent CW system, with the incoherent systems performing inadequately. Coherent CW systems can be significantly improved by using multiple doppler filters. Further, a CW homodyne system needs only one missile-borne laser. The pulsed systems need two.

Going back to basics, the theoretical signal-to-noise (S/N) ratio for a coherent detection system is derived as follows: Given a set of signals:

$P_B \Delta\lambda$ from the background (W)

P_{LO} from the local oscillator

P_S from the return signal

Where the signals are plane waves, parallel at the detector to better than $\pm\lambda/20$, then the signal current (i_s) from the detector is given by:

$$i_s = \eta q \left(\sqrt{P_{LO}} + \sqrt{P_S}\right)^2 \left(\frac{\lambda}{hc}\right) \quad (1)$$

where η = detector quantum efficiency
q = electronic charge
λ = wavelength
h = Planck's constant
and c = velocity of light

We will represent

$$\sqrt{P_{LO}} = \frac{E_{LO}}{\sqrt{2}} \sin \omega_{LO} t, \tag{2}$$

and

$$\sqrt{P_s} = \frac{Es}{\sqrt{2}} \sin \omega_s t \tag{3}$$

Then, substituting into equation (1) and squaring, clearly only the $\sqrt{P_{LO}P_s}$ term produces frequencies within the detector passband and namely $|\omega_{LO} - \omega_s|$. Performing this operation, we obtain:

$$i_s = q\eta \sqrt{P_{LO}P_s} \quad \left(\frac{\lambda}{hc}\right) \tag{4}$$

The ideal shot-noise power (i_n^2) in the total detector current, including background induced current, is given by:

$$i_n{}^2 = 2q \left\{ i_s + q\eta \frac{\lambda}{hc} P_B \, \Delta\lambda \right\} B \tag{5}$$

Clearly, B, the Intermediate Frequency (IF) bandpass is related to the net optical passband by

$$\Delta\lambda = \frac{2B\lambda^2}{c}$$

because

$$f = \frac{c}{\lambda}$$

and

$$df = \frac{-c d\lambda}{\lambda}$$

and because the action of a heterodyne system is to translate twice the pre-detection passband into the IF bandpass.

Thus:

$$i_n^2 = 2q^2 \eta B \left(\frac{\lambda}{hc}\right) \left(\sqrt{P_{LO}} + \sqrt{P_s}\right)^2 + \frac{P_B B \lambda^2}{c} \quad (6)$$

and

$$\frac{S}{N} = \left(\frac{\eta P s \lambda}{2Bhc}\right)^{\frac{1}{2}} \quad (7)$$

in the ideal case. However, measurements have shown real systems to miss this goal by a factor of 2 in voltage (6 dB).

From the above equation, the relations for a system wherein the target is illuminated by a CO_2 laser can be derived. Assuming a beam size smaller than that of the target, the relation is:

$$\frac{S}{N} = \left[\frac{P_L \tau_a{}^2 \tau_D \, \rho' \left(\frac{\pi}{4} D_a^2\right) \tau_s \, \eta \, \lambda}{2R^2 Bhc}\right]^{\frac{1}{2}} \quad (8)$$

where

ρ' = is the diffuse reflectance of the object ($ster^{-1}$)
P_L = the illuminating laser power, watts
τ_D = the illuminator transmission
τ_S = the seeker transmission
D_a = the seeker aperture
η = the detector quantum efficiencies
λ = the wavelength
R = the seeker-target range
B = the IF bandpass
h = is Planck's constant
c = is the velocity of light
τ_a = the atmospheric transmission = $\exp[-\sigma R]$
σ = the extinction coefficient

In this case, all are in consistent units.

The equation may be rewritten in the form as in Army Missile Command report Re-76-4 to provide the contrast to raise power ratio by replacing:

$$\rho' = (\sqrt{\rho t} - \sqrt{\rho B})^2 \tag{9}$$

and squaring to provide, in log form:

$$10 \log_{10} (C/N)^2 = 10 \log_{10} \left\{ \frac{P_L D_a^2 \eta \tau_D \tau s \lambda}{B} (\sqrt{\rho_T} - \sqrt{\rho_V})^2 \right\} -23 -8.68\, \sigma R - 20 \log_{10} r \tag{10}$$

In this case, the units are translated to:

R in km, D_a in cm, λ in micrometers and B in mHz

The conversion factors as well as other constants are absorbed in the 23 dB term. Note the discrepancy (of 3dB) between this and the corresponding term of the similar equation of RE-76-4. Also, the atmospheric transmission is missing in the first term of our equation.

By straightforward techniques, it is possible to derive contrast to noise ratio for the incoherent system as:

$$\frac{S}{N} = \frac{D^* P_L \tau_S \tau_D \tau_A^2 \left(\frac{\pi}{4}\right) D_a^2 \rho'}{R^2 \sqrt{A_D B}} \tag{11}$$

D^* = Detector detectivity, cm Hz $^1/_2$ W
A_D = Detector area, cm^2

Other terms are, as previously defined, in consistent units.

This equation may be rewritten in a manner consistent with Equation (10) and its units, to find the contrast to noise-power ratio as:

$$10 \log_{10} (C/N)^2 = 20 \log_{10} \frac{D^* P_L \tau_S \tau_D D_a^2 (\rho t - \rho_B)}{\sqrt{A_D B}} \tag{12}$$

$$= -242 \quad -17.37\ \sigma R \ -40 \log_{10} r$$

In evaluating required C/N values, the prior (RE-76-4) criteria or a $0.01 P_{FA}$ and $0.99\ P_D$ have been modified slightly to the criteria of one false alarm per second, with $P_D = 0.99$. For a CW system, or a high Pulse Role Frequency (PRF) pulse system, this definition appears more meaningful than an explicit false alarm probability. Under these constraints the false alarm rate for a homodyne system is given approximately by:

$$N = \frac{B}{\sqrt{3}} \left[e^{-\frac{1}{2}\left(\frac{V}{\sigma}\right)^2} \right] \tag{13}$$

For example,

$$N(B = 5 \text{ mHz}; \frac{V}{\sigma} = 5.45) = 1.02 \text{ per second.}$$

With 5 km range gating and a 300 pps system, $V/\sigma = 4.5$ would provide $N \cong 1$. The CW system can use a lower S/N ratio due to a potentially narrower system passband of about 50 kHz. Its threshold can be set at 4.5 to achieve the same false alarm rate.

By straightforward methods, we calculate the required signal level to achieve a P_D of 0.99 and find a value of $V/\sigma = 2.35$ for the pulse system. The CW system can probably run at a much lower level in practice . . . say $V/\sigma = 1.0$. Thus, for the three systems we have:

$$\text{Pulsed: Required} \quad \frac{S}{N} = 7.8 \text{ or } 17.8 \text{ dB} \tag{14}$$

$$\text{Pulsed and range gated:} \quad \frac{S}{N} = 6.85 \text{ or } 16.7 \text{ dB} \tag{15}$$

$$\text{CW:} \quad \frac{S}{N} = 5.5 \text{ or } 14.8 \text{ dB} \tag{16}$$

Figure 1 shows achievable ranges for the several types of pulsed and CW laser seeking systems.

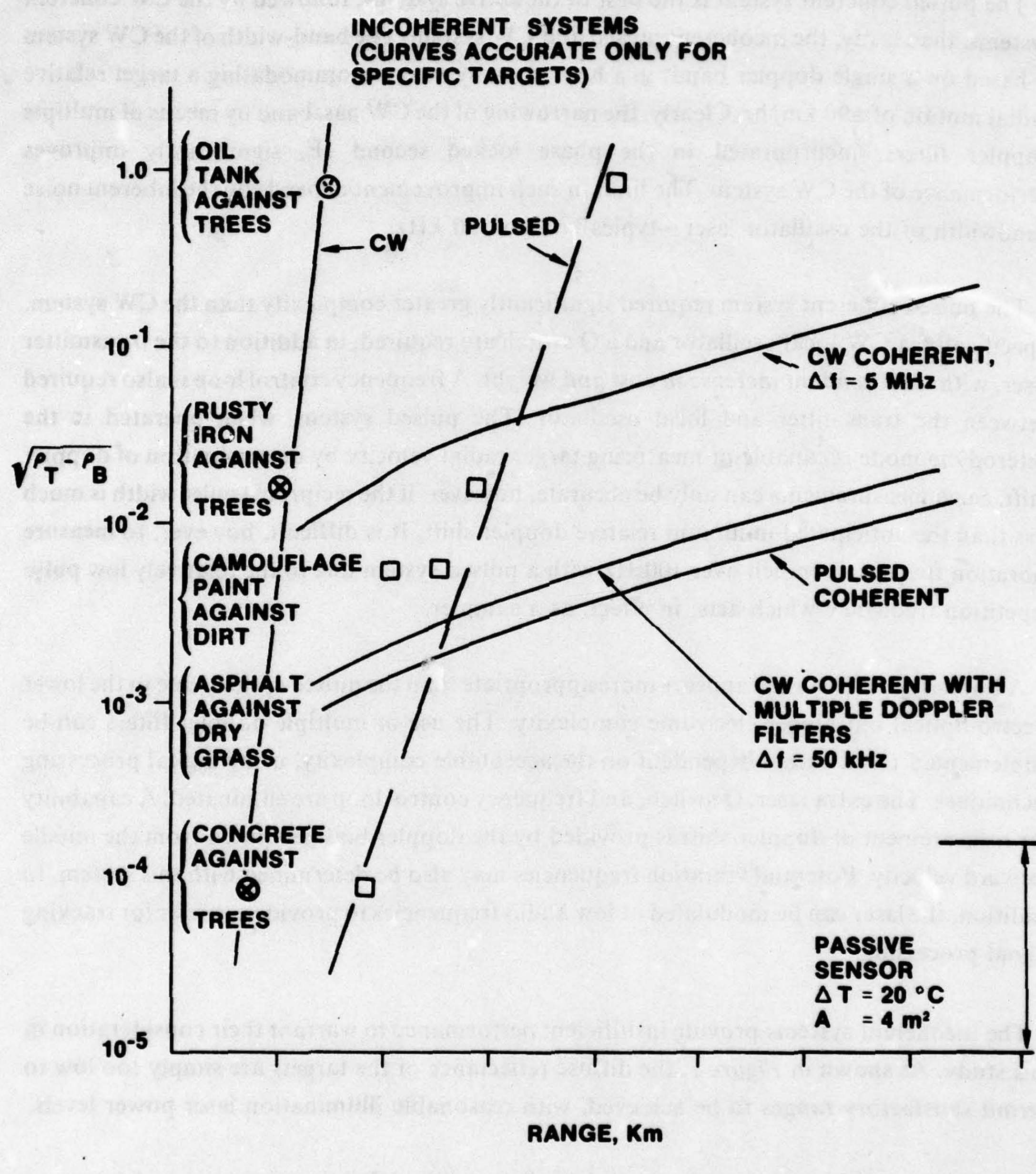


Figure 1. Comparison of seeker alternatives.

The pulsed coherent system is the best of the active systems, followed by the CW coherent systems, then lastly, the incoherent pulsed and CW system. The band-width of the CW system is based on a single doppler band, in a homodyne system, accommodating a target relative radial motion of ±90 km/hr. Clearly, the narrowing of the CW passband by means of multiple doppler filters, incorporated in the phase locked second IF, significantly improves performance of the CW system. The limit in such improvement depends on the inherent noise bandwidth of the oscillator laser --typically about 30 kHz.

The pulsed coherent system required significantly greater complexity than the CW system. Specifically, a CW local oscillator and a Q switch are required, in addition to the transmitter laser, with the attendant increase in cost and weight. A frequency control loop is also required between the transmitter and local oscillator. The pulsed system, when operated in the heterodyne mode is capable of measuring target radial velocity by determination of doppler shift. Such measurements can only be accurate, however, if the reciprocal pulse width is much less than the anticipated minimum relative doppler shift. It is difficult, however, to measure vibration frequencies much over 100 Hz with a pulsed system due to the relatively low pulse repetition frequency which acts, in effect, as a sampler.

A homodyne CW system appears more appropriate than the pulsed system, due to the lower electro-optical but higher electronic complexity. The use of multiple doppler filters can be implemented to an extent dependent on the acceptable complexity, using digital processing techniques. The extra laser, Q switch, and frequency control loop are eliminated. A capability for measurement of doppler shift is provided by the doppler bias generated from the missile forward velocity. Potential vibration frequencies may also be determined with this system. In addition, the laser can be modulated at low audio frequencies to provide a carrier for tracking signal processing.

The incoherent systems provide insufficient performance to warrant their consideration in this study. As shown in *Figure 1*, the diffuse reflectance of the targets are simply too low to permit satisfactory ranges to be achieved, with reasonable illumination laser power levels.

Figure 2 shows a general configuration (implementation) for an active system. A common scanning unit scans the transmitting and receiving optics simultaneously. Its precision must be such as to cause the beams to track to an accuracy of about 0.25 mrad, for parameters previously given, to achieve adequate heterodyne detection.

After preamplification, the detector signal output frequency is of the order of 55 MHz, due to a combination of missile forward velocity and gimbaled-look angle. This frequency is

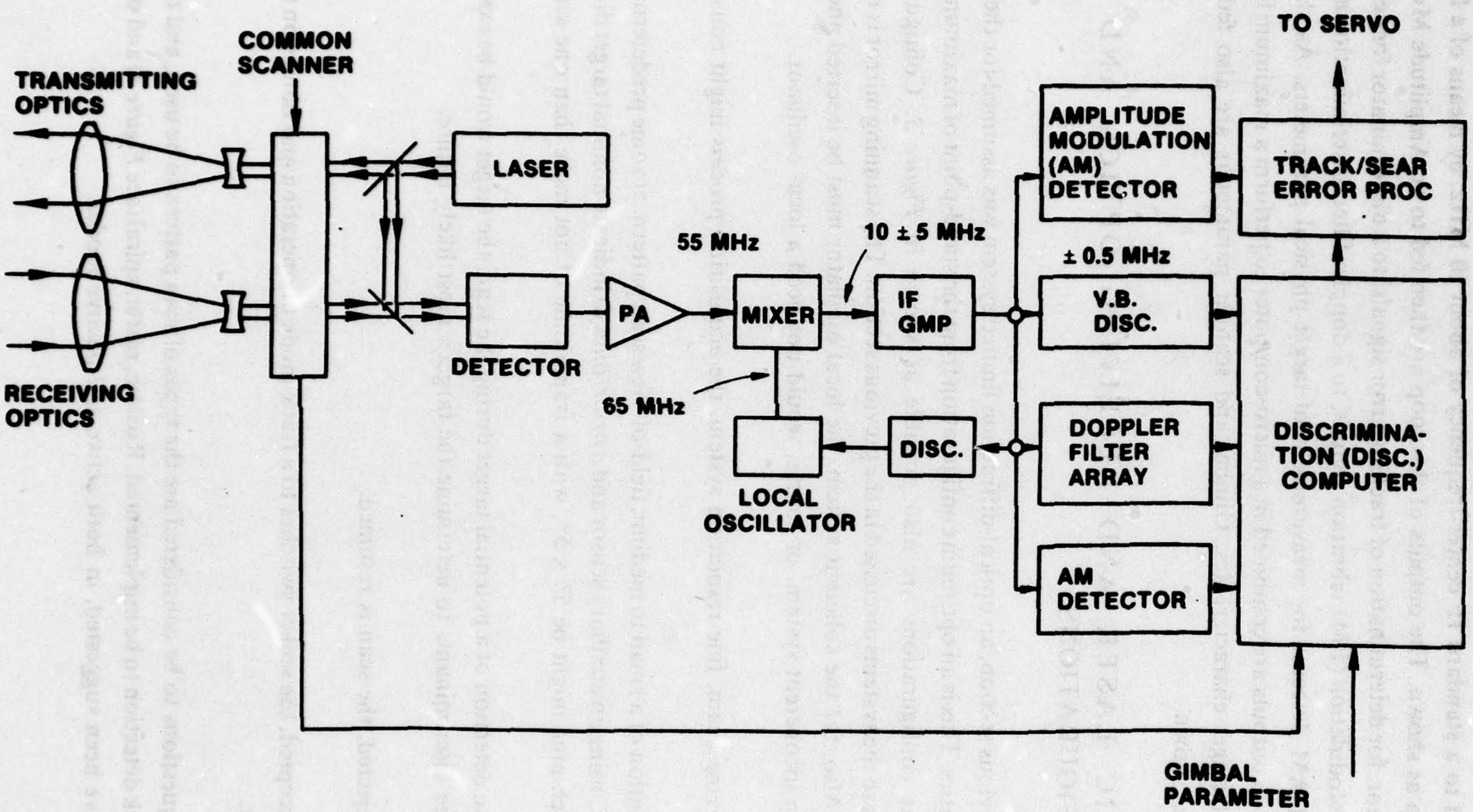


Figure 2. Active discrimination seeker configuration.

heterodyned to a standard IF center frequency of about 10 MHz, by means of a frequency control loop as shown. The outputs of this loop are then fed to an Amplitude Modulation (AM) detector, for determination of tracking error signals; to a discriminator for detection of Frequency Modulation (FM) vibration signals; to a doppler filter/discrimination array, and to a second AM detector for measurement of target physical parameters. As shown, the discrimination outputs are combined in a micro-computer to perform a maximum likelihood ratio test of target characteristics. Gimbal and scanner parameters are also fed into the computer, as shown.

B. BASIC LASER AND RECEIVING OPTICS AND SCAN CONFIGURATIONS

In the previous section, an optical-diffraction limited system was assumed for the laser and receiving optics. This is an optimum configuration from the stand-point of maximum signal to noise. Other configurations are also possible as shown in *Figure 3*. Configuration 3a corresponds to the systems discussed in the previous section. The scanning mirror is not shown for clarity. Also, for the coherent system, the local oscillator must be inserted ahead of the detector. An incoherent system, of course, would not need a local oscillator.

For a narrow beam, fine resolution system, the acquisition process might consist of:

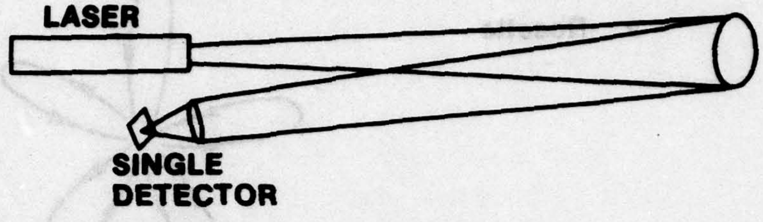
(1) Initiation of a small to medium field-of-view scan pattern, at some predetermined time after launch, using an auxiliary sensor and *a priori* data to indicate nominal target direction. A typical search area might be 5° x 5°, with a frame time of not more than one second.

(2) Upon detection of a potential target during the scan, the target would be examined by means of the discriminants to determine the target's most likely nature.

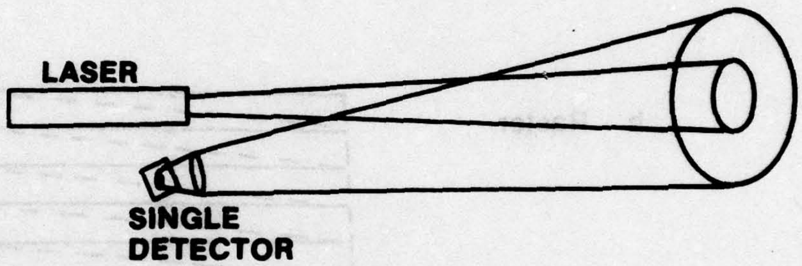
(3) If rejected, the scan is resumed.

(4) If accepted, the seeker switches to a track mode of operation and homes on the target, to intercept.

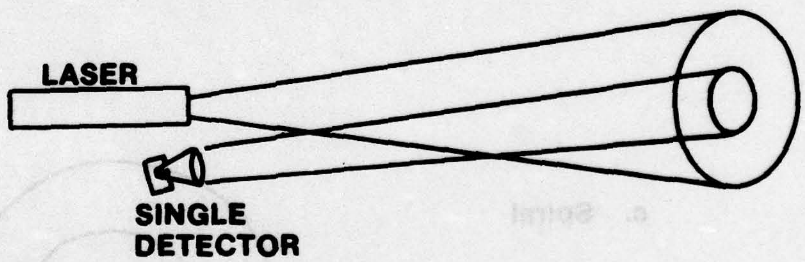
Some key questions to be considered are the types of scan pattern to be used, and the type of search/track detection to be implemented. Rosette, raster, spiral (see *Figure 4*) and other types of scans have been suggested, in both active and passive modes.



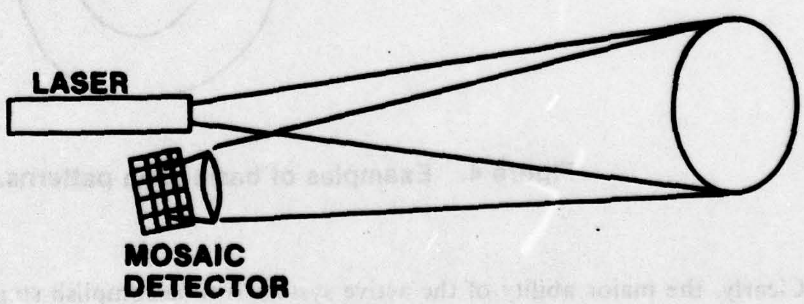
a. Narrow Beam Laser and Fine Resolution, Single Detector



b. Narrow Beam Laser and WFOV Single Detector



c. Wide Beam Laser and Fine Resolution, Single Detector



d. Wide Beam Laser and Fine Resolution, Wide-Field of View (WFOV) Mosaic

Figure 3. Basic laser and receiver configurations.

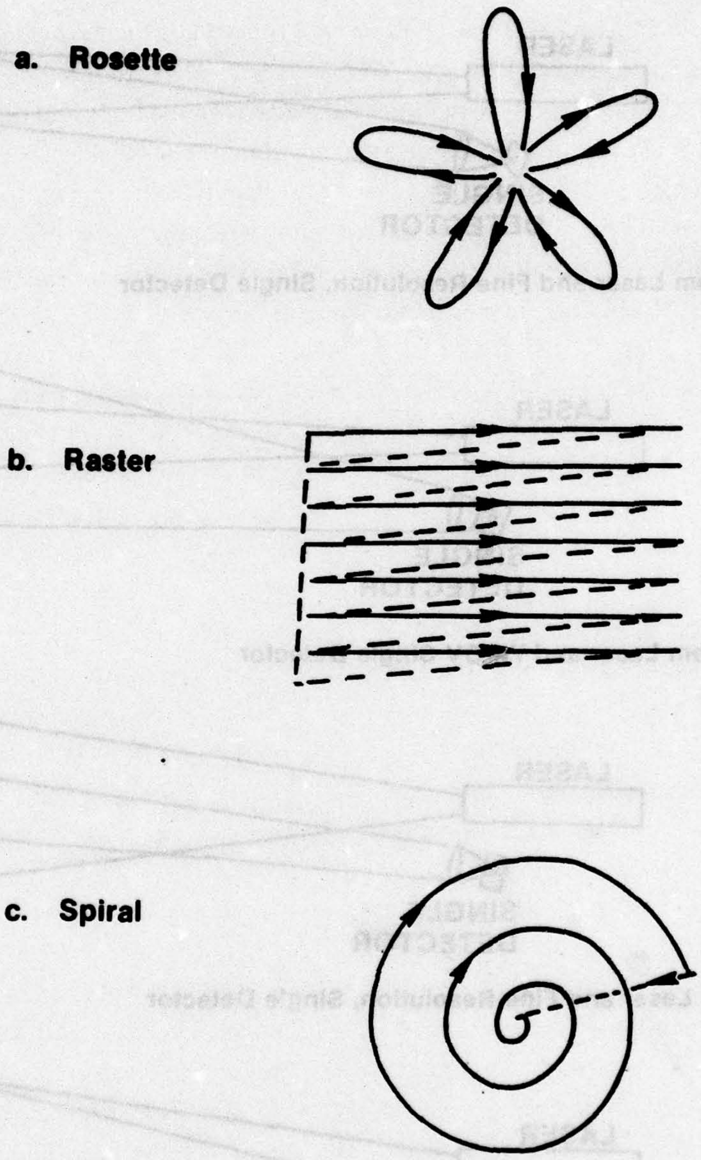


Figure 4. Examples of basic scan patterns.

Clearly, the major ability of the active system is to accomplish step 2 of the acquisition process, while calculations have shown that a passive wideband system may provide better range capability than the active systems. This factor suggests, tentatively at least, the use of a passive system for initial search and, at best, the use of both active and passive modes in the process.

In the choice of scan patterns, some combination is needed which provides optimal track information and optimal search characteristics. Neither the rosette nor the raster scan are optimum for both, although each provides good capability in the track and the search modes, respectively. In this case, the ratio of search area to Instantaneous Field-of-View (IFOV) area is about 10^5:1. Thus, the use of a large field rosette for search would appear to create a highly non-optimum scan with many holes and/or overlaps, while the raster is ideal. Conversely, during track, the potentially high duty cycle of a rosette scan, which has a capability for post detection limited AM tracking, makes its implementation ideal.

Thus, a potentially suitable approach would use a passive or active raster scan for initial search, dwelling on the position of detected potential targets with a rosette scan active system to examine their characteristics, and finally tracking the selected object with an active or passive rosette scan. A spiral scan might be implemented as a potential acquisition pattern, in lieu of the raster scan.

Configuration 3b utilizes a wide FOV receiver and a narrow laser beam. This configuration would permit the laser beam to scan within the stationary FOV of the receiving optics. This approach would eliminate some potential problems of boresight alignment between laser and receiver for the 3a configuration. Also, Configuration 3b would not have possible problems with the finite pulse propagation times. At long ranges, Configuration 3a could require an angular lag in the receiving optics scan to allow for the lag in returns from the laser.

Configuration 3c is more realistic. In general, the laser output beam will not be diffraction-limited, so that the beam will be larger than the resolving power of the receiving optics. For this case, the signal-to-noise will be reduced roughly as the square of the beam's diameter. Possible scanning configurations would be a common scan mirror for both the laser and the receiving optics (as in *Figure 2*) or a configuration in which the receiving optics are scanned within the larger area illuminated by a stationary laser beam. For Configurations 3b and 3c, the system resolving power is determined by the smaller of the laser or receiving optics resolutions.

Configuration 3d shows an approach which would eliminate the need for any mechanical scanning. It consists of a wide FOV laser illuminator and a mosaic detector array to cover the same area. This configuration would probably be limited to an incoherent system because of the difficulties in matching the local oscillator wavefront simultaneously over a wide angular FOV. This configuration will be discussed in Section 3E in conjunction with depth signature discrimination.

3. ACTIVE SEEKER DISCRIMINATION TECHNIQUES

The key attribute of the active system is its potential ability to discriminate a real target from a complex background containing many false targets. Many potential discriminants have been postulated, including:

- Target radial and tangential velocities,
- Vibration levels and frequencies,
- Polarization effects,
- Target shapes and sizes,
- Determination of surface texture by reflectivity measurements.

Some appear viable, others have less likelihood of success. In the following section, the discriminants will be discussed.

A. RADIAL TARGET VELOCITY

One of the potentially powerful discriminants appears to be that of motion discrimination. A laser illuminated target yields a combination of both AC and DC components, the former results from vibration of the vehicle and the latter due to its motion along the ground. Vibration measurements are considered in the following section; movement is considered in this section.

The measurement of movement is hampered by four things:

- The direction of vehicle movement.
- The noise spectra of the laser.
- The forward motion of the seeker in the missile.
- The pulsed nature of the signal if a pulsed coherent seeker is used.

The direction of vehicle motion appears, at first glance, to present a serious problem as the coherent seeker is incapable of measuring tangential target velocities (normal to the line-of-sight) to any reasonable accuracy. The target can move relatively slowly, normal to the line-of-sight, and remain undetected.

The vehicles, if tanks, will tend to move towards the missile launch area. However, it is assumed that the vehicle motion is equally likely in any direction, with respect to the missile flight path. Then, considering only the horizontal component of velocity and neglect the missile viewing angle,

$$V_r = V \sin \theta \tag{17}$$

with $p(\theta) = 1/2\pi$

Since $P(V_r)dV_r = P(\theta)\, d\theta$,

$$P(V_r) = 4 \left\{ \left(\frac{1}{2\pi} \cdot \frac{1}{\sqrt{V^2 - V_r^2}}\right) \right\} \tag{18}$$

The factor of four stems from the reduncancy between the four quadrants.

$$\text{Thus,} \quad P(\hat{V}_r \geq V_r) = \frac{2}{\pi} \int_{V_r}^{V} \frac{dV_r}{\sqrt{V^2 - V_r^2}} \tag{19}$$

$$= 1 - \frac{2}{\pi} \sin^{-1} \frac{V_r}{V} \tag{20}$$

As will be seen, a value of V_r of 0.3 m/sec is a reasonable radial speed detection threshold. Assuming that the target moves at only 1 m/sec, slower than walking speed, the likelihood of a radial velocity component greater than 0.3 m/sec is about 80 percent. Thus, the lack of tangential velocity detection capability may be irrelevant.

The noise spectra of the laser plays a big part in determining the minimum detectable velocity. This is because the apparent laser bandwidth tends, in a gross sense, to mask the doppler shift from low velocity targets. The doppler shift is given by:

$$f = \frac{2V}{\lambda}, \text{ then } V = \frac{\lambda \Delta f}{2} \tag{21}$$

So that a 30 kHz bandwidth laser would mask a peak-to-peak doppler shift of:

$$V = \frac{10.6 \times 10^{-6} \times 3\ 3\ 10^{4}}{2}$$

$$= .159 \text{ m/sec}$$

This figure probably represents a 2σ value, as an actual velocity shift of this value would shift the frequency 30 kHz, while the real noise bandwidth is ±15 kHz.

The forward velocity of the missile presents a problem, as it completely masks a motion of the target, and it creates a significant doppler offset in the process. A 600 ft/sec missile velocity causes a 40 MHz doppler shift of the return signal. If the system is designed to measure the relative doppler shift between the target and its adjacent background, however, the system becomes workable with limitations. The offset is an advantage for a CW system in that it permits determination of vehicle motion direction.

If the seeker is designed as an FM system which measures (and perhaps tracks on) the frequency difference between the target and the background, the seeker measures relative, rather than absolute, doppler shift.

The measurement threshold is limited by laser noise, as previously mentioned, by system S/N ratio, and by the gimbal and scan angles. The variation in the relative velocity with gimbal or scan angles is given by

$$V_{rel} = V_m \cos \phi \tag{22}$$

where V_m is the missile velocity, and ϕ is the gimbal angle with respect to the missile velocity vector.

$$\text{Then,}\quad d(V_{rel}) = -V_m \sin\phi \, d\phi \tag{23}$$

If the maximum gimbal angle is 20 deg, the scan angle is 5 mrad.

Then, for $V_m = 200$ m/sec,

$$dV_{rel} = 200\,(\sin 20°)\,(0.005)$$
$$= 0.34 \text{ m/sec}$$

Clearly, this parameter dictates a small scanned field-of-view and small gimbal angles when discrimination is being performed. Alternatively, the relative target angles must be measured and corrections determined by the data processing system.

Doppler measurements are simple with a CW coherent system, the return signal frequency may be detected in a simple discriminator. In a pulsed system, however, the detection process is a little more difficult, but possible. The pulse spectra in the seeker IF amplifier must be compared with the transmitted pulse spectra to determine frequency shift. The accuracy to which this can be performed is clearly dependent on carrier S/N ratio; however, the precise relation must be determined by further analysis. Further, the pulse repetition rate must be high compared to the scan frequency, typically on the order of 300 pps; such rates are feasible, although difficult, for Q switched pulsed lasers.

B. VIBRATION SENSING

Another unique discriminant for differentiating between real and false targets would be the vibration of the target. Clearly, natural objects can't vibrate with nearly the same spectra as a tank or truck, for instance. The seeker, in this mode, is configured to measure the frequency modulation spectra generated by target Aircraft (AC) motions. Unfortunately, this discriminant appears marginal at best.

The limitations of this technique stem from the following:

- **The laser bandwidth**
- **The amplitude of the target vibration spectrum**
- **The missile vibration and turbulence in flight**

- Atmospheric turbulence effects on doppler shift
- Frequencies must be lower than half the seeker scan frequency
- The seeker must use a CW laser or a high pulse repetition frequency

The first item is of major consequence. As a typical laser bandwidth is about 30 kHz, the target vibration level must be of sufficient amplitude to generate FM sidebands having a Radiometric Seeker (RMS) value of at least the 30 kHz value to be detected, let alone measured.

Figure 5 shows Mil E 5400 vibration for helicopters and aircraft. These will be used as a worst case for our analysis. Using curve IV, the worst case, one calculates maximum RMS vibration velocities of 0.11 m/sec at 20 Hz, and 0.14 m/sec at 72 Hz. The RMS doppler FM, due to these vibrating sources, is 22 kHz and 28 kHz, respectively. Thus, unless the laser bandwidth can be reduced, or the target vibration levels increased, detection will be difficult, and measurements marginal at best.

Detection of vibration is desired under non-moving target conditions, where the engine is idling, or machinery is running to create the vibration source. Otherwise, with target motion, the target is detectable by the static doppler shift means previously described.

Missile vibration would not significantly degrade vibration detection performance if the laser bandwidth is reduced. *Figure 6* shows the operating vibration acceleration power spectra of a Maverick missile. This power spectra may be divided by $(W)^2$ to find the vibration velocity power spectra. Integrating, one calculates an RMS velocity of 0.03 m/sec, well below the target vibration values.

Atmospheric turbulence, as well as missile turbulence, will create an AC phase distortion in the incident and reflected wave front. Such phase distortion will act to effectively increase the bandwidth of the laser oscillator by adding relatively low frequency FM sidebands to the existing doppler shifted carrier. These effects are not expected to be limiting relative to the previously mentioned laser noise effects.

For vibration signature discrimination, the seeker must use CW or a high pulse repetition laser source. Further, scanning of the laser across the target acts as a sampler and effectively limits the measurement of vibration frequencies to half the scan frequency. Clearly, the PRF of a pulsed laser cannot be the real limit as the PRF must be at least twice the scan frequency to

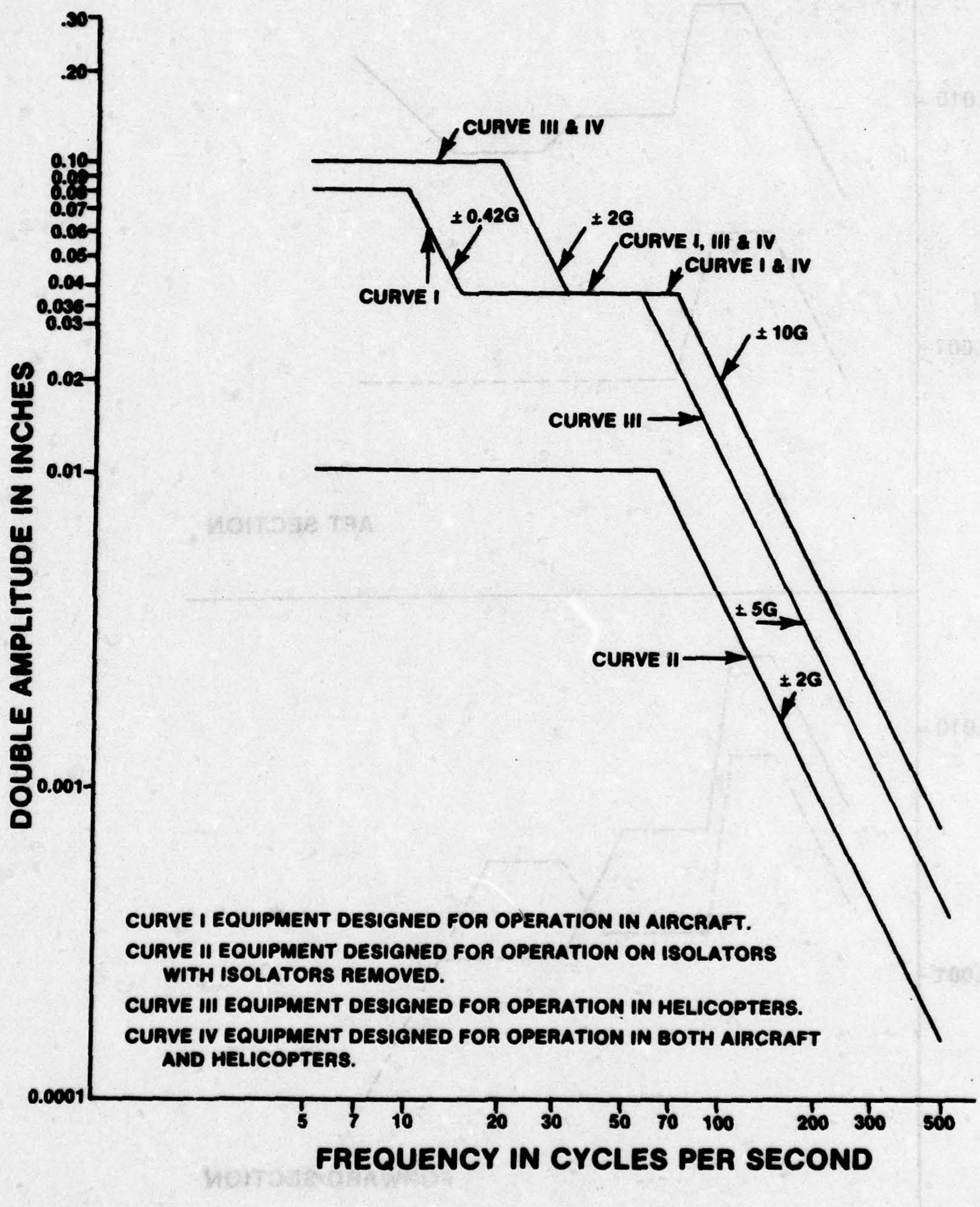


Figure 5. Mil E 5400 vibration levels.

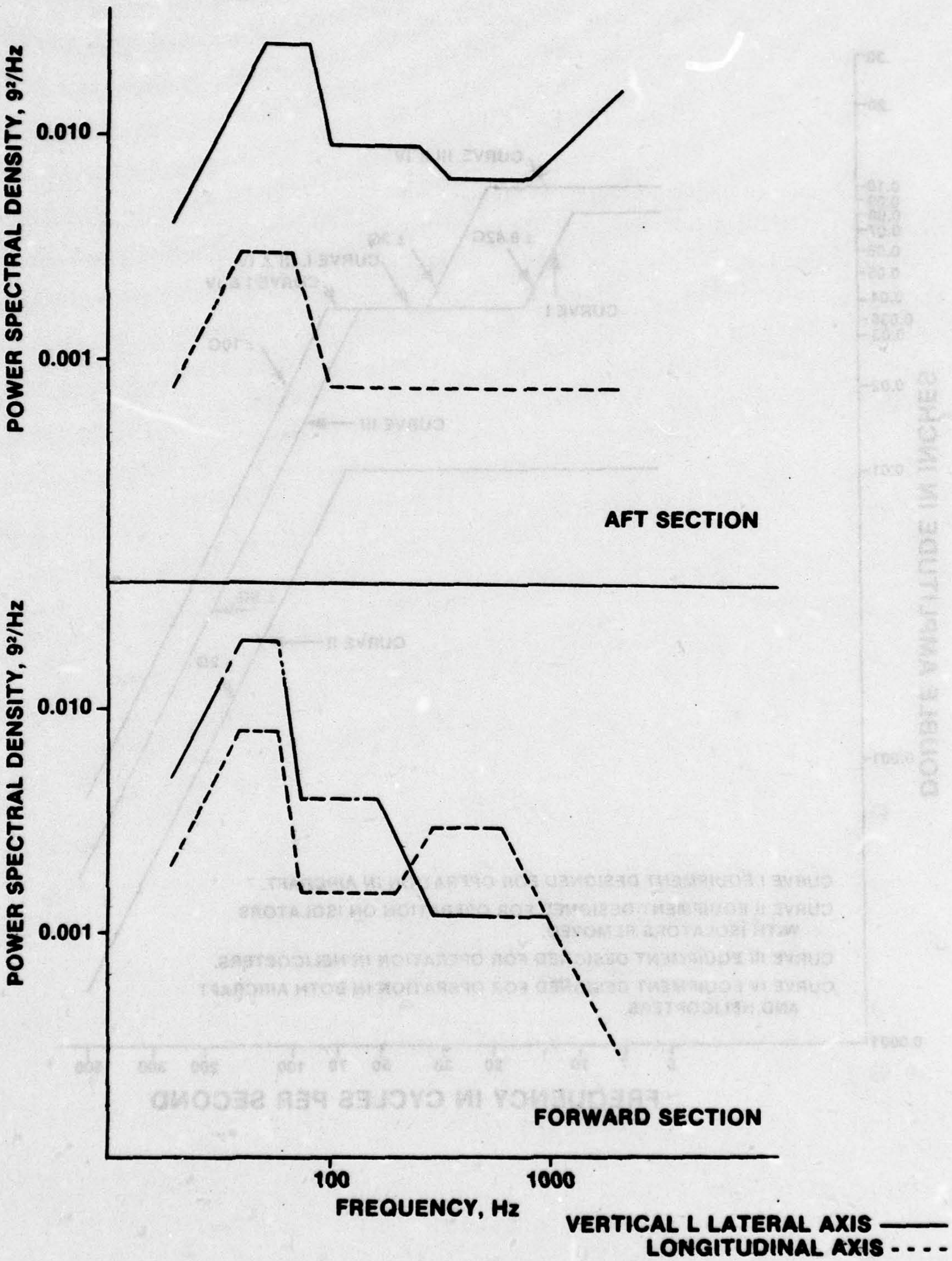


Figure 6. (U) Maverick missile operating vibration conditions.

make the pulsed system work in the first place. The CW system is to be preferred, however, from a discrimination processing point of view.

C. TANGENTIAL TARGET VELOCITY

The tangential component of target motion cannot be detected by doppler as indicated in Section 3E. A crude determination can be made by comparing the relative movement from frame to frame. The accuracy in detecting frame-to-frame movement is limited by the optical angular resolution and the gimbal stability. The limiting accuracy is probably of the order of two resolution elements per frame. Assuming adequate gimbal stabilization, this accuracy would be about 15 mrad per second. This value assumes a 0.25 mrad resolution, and a scan rate of 30 frames per sec. At an acquisition range of 3 km, these values result in a single-frame speed measurement of 164 km/hr. Thus, lower speeds are only detectable over a relatively long period of time. These measurements could, in concept, be made from a stationary platform to an accuracy of about 1 mrad/sec, or 1.1 km/hr at 3 km range. The problem, however, is the relative velocity of the missile. At a gimbal angle of only 5 deg, the target has an apparent tangential motion of 100 km/hr. A method of sensing tangential motion with respect to the background is needed.

D. POLARIZATION EFFECTS

Measurements of polarization effects in reflected 8-13 micron IR signals have been made, as have measurements of depolarization of active 10.6 micron signals by targets of differing shapes and textures. These data indicate that illumination of targets at high incident angles to their surface provides significant polarization effects. They also show that significant depolarizing effects may be noticed when viewing targets of high aspect ratios. However, the former effect requires use of a separate, non-co-located illumination source; while the depolarizing effects is predicated on the assumption of oddly shaped targets.

Thus, the tentative conclusion is the same as in studies; namely that polarization effects do not provide a consistently useful discriminant.

E. TARGET DEPTH SIGNATURE DISCRIMINATION

Figure 7 illustrates the elements of depth discrimination. For convenience, it is assumed that a single-detector instantaneous FOV is filled by the target so that most of the laser reflected energy as seen by the detector is due to the target alone. The amplitude of the target returns as a

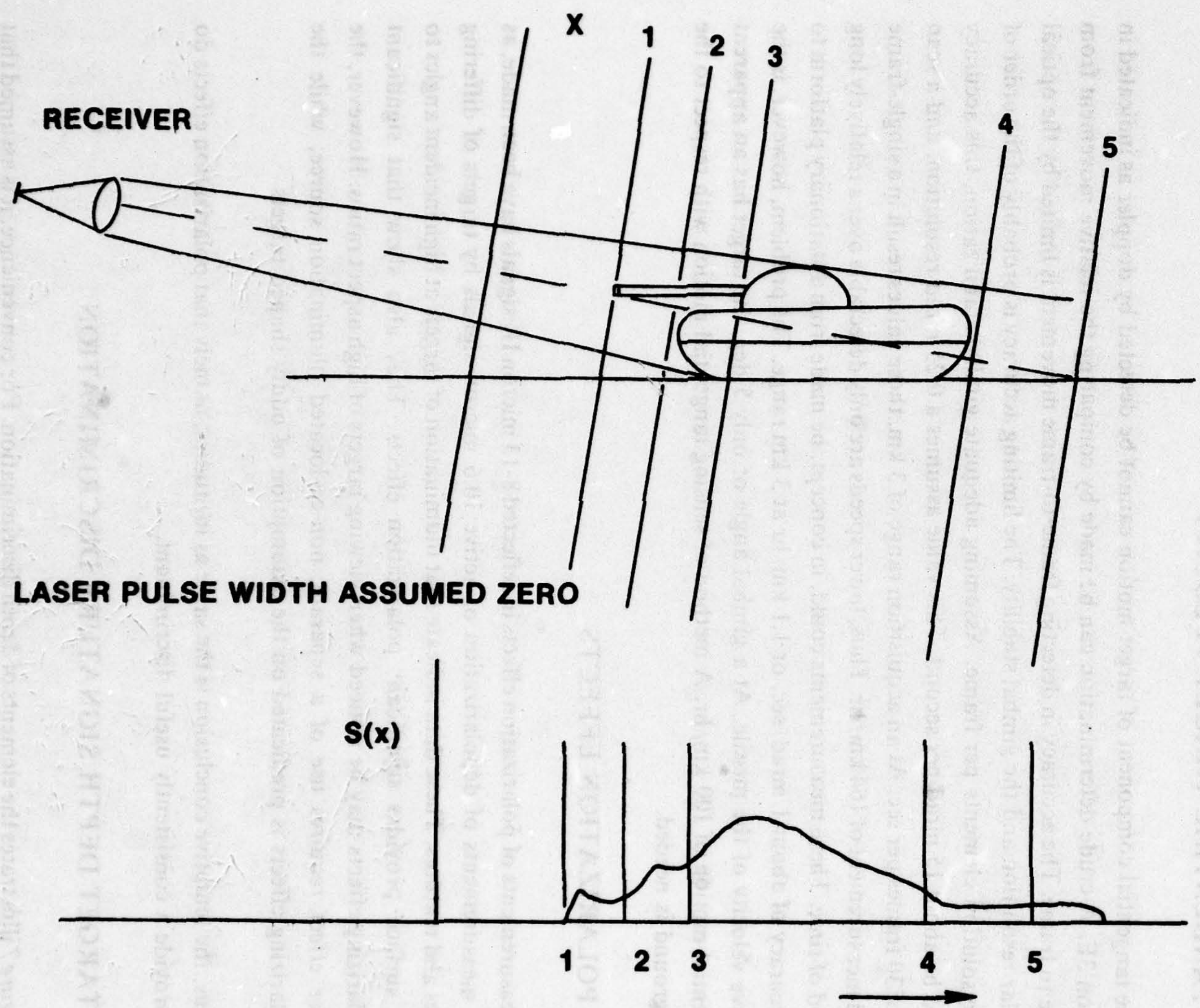


Figure 7. Idealized target depth signature.

function of target depth, S(x), is a function of the reflectance, r, and the target area, A. Therefore, as a function of depth, the target return is proportioned to S(x) given by

$$S(x) = r(x)\ A\ (x) \tag{24}$$

As shown in *Figure 7*, the initial signal is due to the target barrel (1 to 2) which is low because of the relatively small area. As to the body of the target (2 to 3) is intercepted, the signal increases due to the greater area, and the more oblique angles. The target signal drops off at (4) and the remaining returns are due to spillover from the background. As shown, a zero pulse width is assumed. To obtain the output with a finite pulse width, the actual pulse distribution is convolved with S(kx).

$$s'(t) = S(kx) * P(t) \tag{25}$$

where K = 2/c
c = velocity of light
P(t) = the time intensity distribution of the laser pulse.

The above only applies to a one dimensional case. For a real three dimensional case, the problem of deconvolution is much more complex.

The idealized situation described above applies only if the instantaneous resolution of the system (either laser beam width or detector IFOV) is smaller than the target angular subtense. If the system resolution becomes significantly larger than the target,returns from the target surroundings will swamp the target signature.

Figure 8 shows the ideal case where the laser foot-print is smaller than the target. As shown, the returns from the target and the background can be easily distinguished. *Figure 9* shows the effect on the laser returns for different target ranges. At 1 km, the beam footprint is assumed to just equal the target width. As the range is increased, the beam footprint will increase in size relative to the target and the laser returns from the target surrounding will increase. It should be noted that the target surroundings include the target foreground as well as the background. As shown in *Figure 9*, at a range of 3 km, the target return is approximately 1/9 the return from the surroundings (assuming equal reflectance of target and surroundings). If we assume a limiting value for the ratio of system resolution to target angular subtense, then a relation between system aperture and operating range can be established.

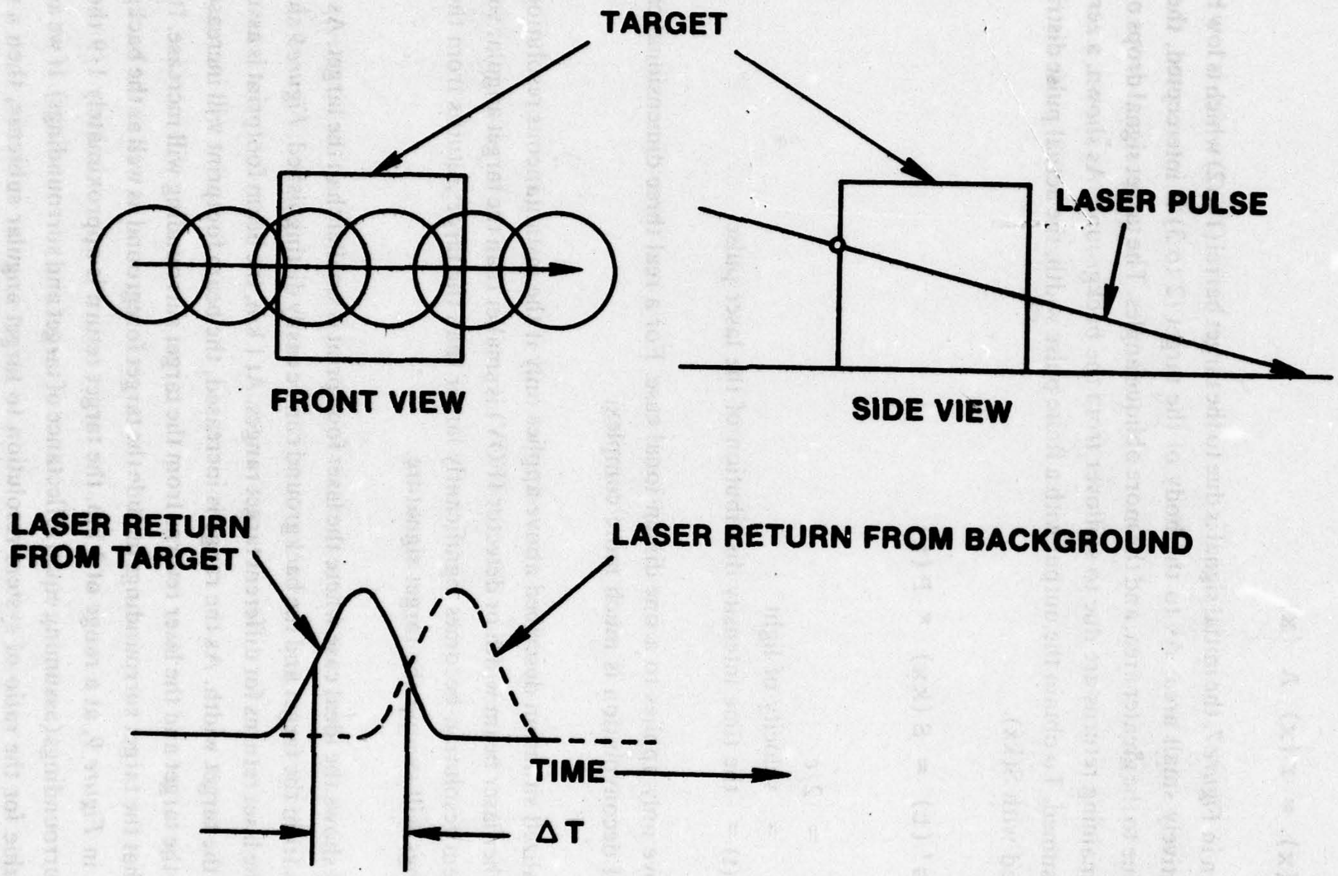


Figure 8. Laser scan through target and background.

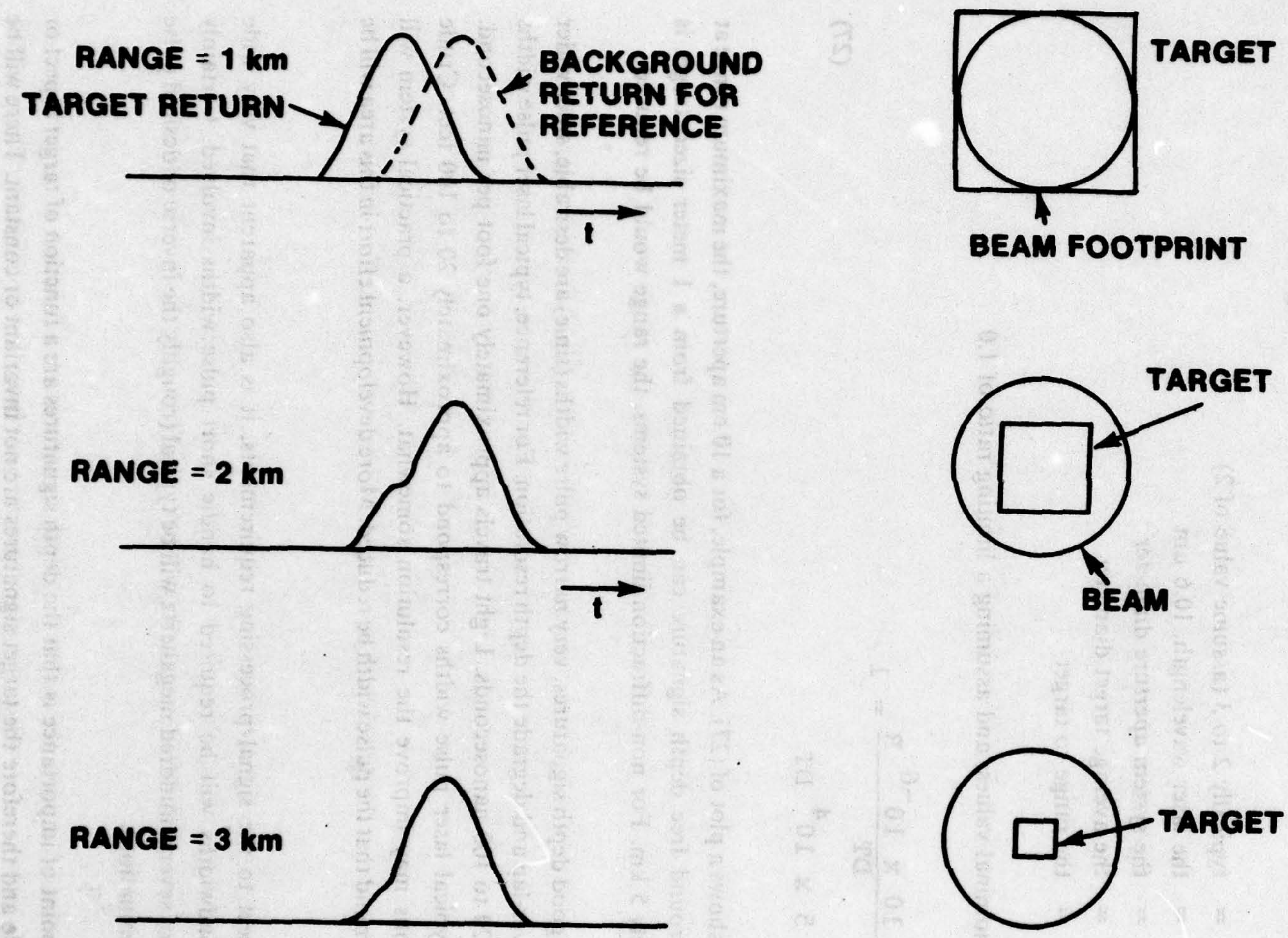


Figure 9. Laser return pulse waveforms for various target ranges.

$$\text{Limit Ratio} = \frac{\text{System Resolution}}{\text{Target Subtense}} = \frac{\frac{k\lambda}{D}}{\frac{T}{R}} \tag{26}$$

where k = typically 2 to 3 (assume value of 2)

λ = the laser wavelength, 10.6 μm

D = the system aperture diameter

T = the average target diameter

R = the range to target

Inserting nominal values, and assuming a limiting ratio of 1.0

$$\frac{2 \times 10 \times 10^{-6} R}{DT} = 1$$

$$R = 5 \times 10^{4} DT \tag{27}$$

Figure 10 shows a plot of (27). As an example, for a 10 cm aperture, the maximum range at which a surround free depth signature can be obtained from a 1 meter sized target is approximately 5 km. For non-diffraction limited systems, the range would be reduced.

To obtain good depth signatures, very narrow pulse widths (time) are desirable, since wider pulses will over-lap and degrade the depth resolution. For reference, typical laser pulse widths range from 20 to 100 nanoseconds. Light travels approximately one foot per nanosecond. Therefore, typical laser pulse widths correspond to approximately 20 to 100 feet. Crude deconvolutions may improve the resolution somewhat. However, a practical system will probably demand that the pulse width be reduced. More development effort in this area will be required.

With respect to the signal processing requirements, it is also apparent that very wide electrical bandwidths will be required to handle short pulse widths involved. Certainly bandwidths of several hundred megahertz will be typical (roughly the inverse of desired pulse width discrimination).

Another point of importance is that the depth signatures are a function of target aspect or viewing angle and therefore the target signatures are not invariant or constant. There will be limits to minimum and maximum apparent depth. However, these will probably be the only target signature invariants. In addition, the IFOV of the detectors will not be centered on the

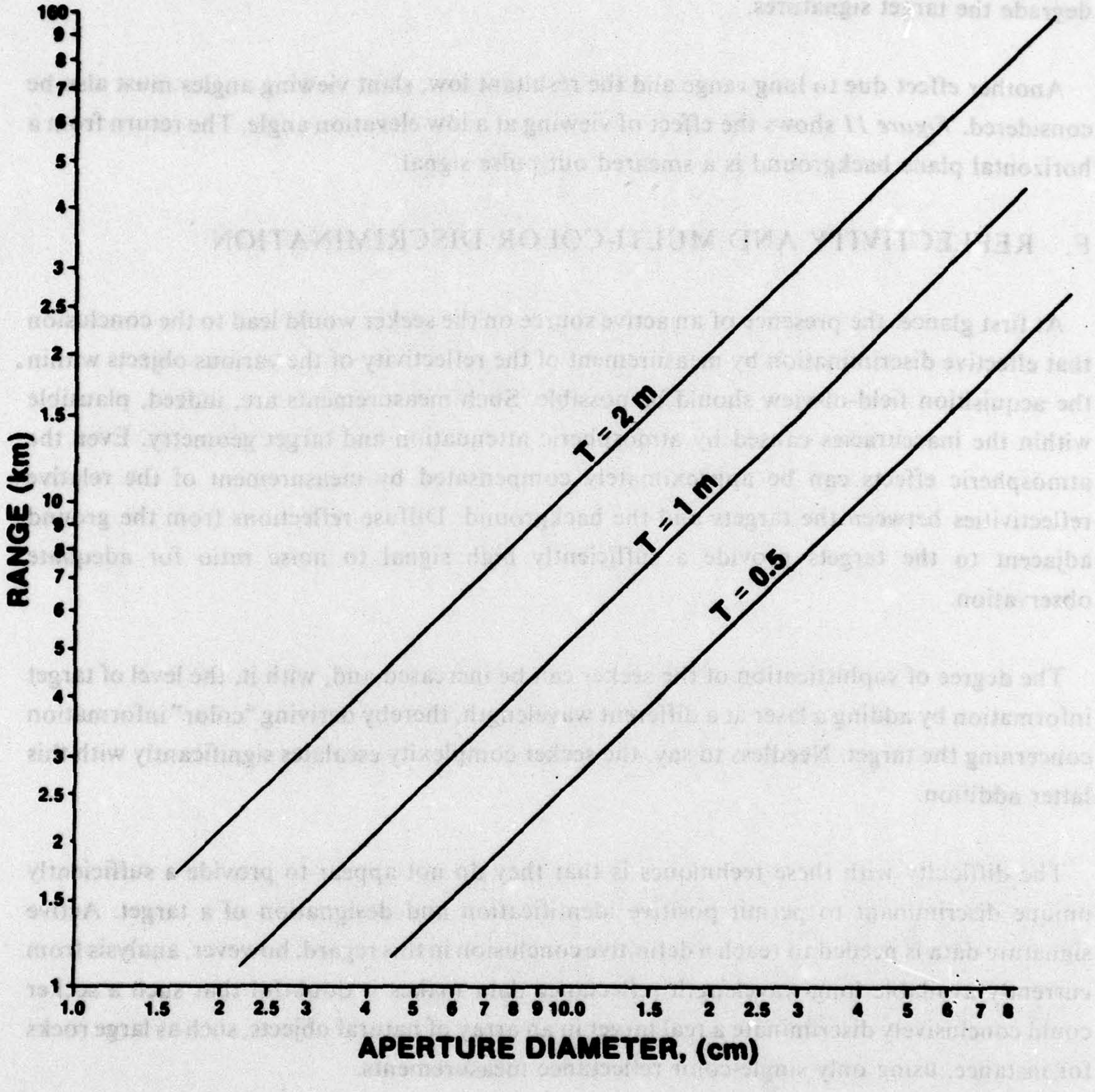


Figure 10. Limiting range versus aperture for depth signature discrimination.

targets so that some background returns will typically be added to the target returns which will degrade the target signatures.

Another effect due to long range and the resultant low, slant viewing angles must also be considered. *Figure 11* shows the effect of viewing at a low elevation angle. The return from a horizontal plane background is a smeared out pulse signal.

F. REFLECTIVITY AND MULTI-COLOR DISCRIMINATION

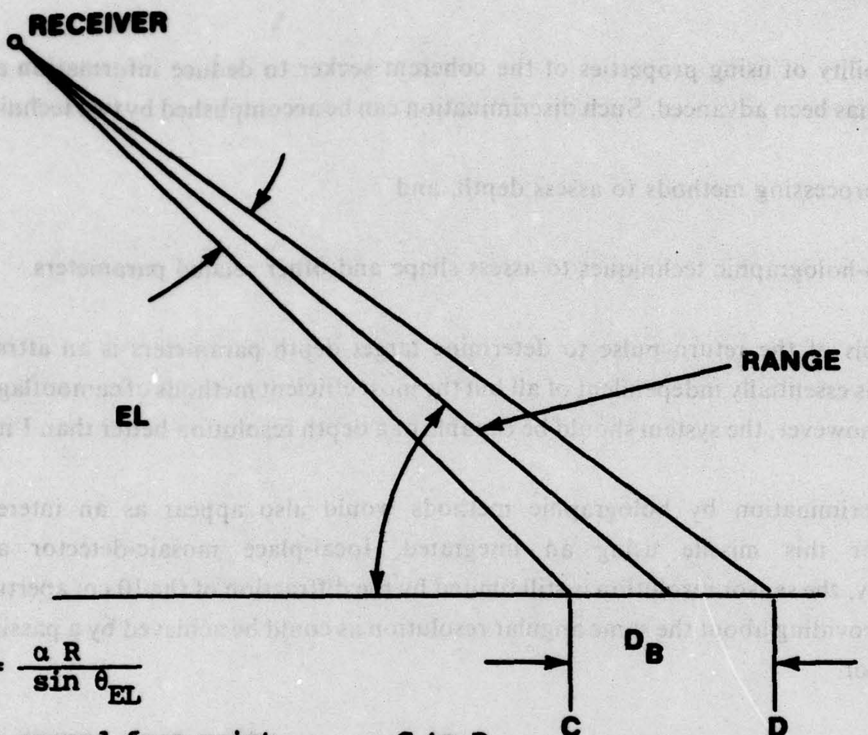
At first glance, the presence of an active source on the seeker would lead to the conclusion that effective discrimination by measurement of the reflectivity of the various objects within the acquisition field-of-view should be possible. Such measurements are, indeed, plausible within the inaccuracies caused by atmospheric attenuation and target geometry. Even the atmospheric effects can be approximately compensated by measurement of the relative reflectivities between the targets and the background. Diffuse reflections from the ground adjacent to the targets provide a sufficiently high signal to noise ratio for adequate observation.

The degree of sophistication of the seeker can be increased and, with it, the level of target information by adding a laser at a different wavelength, thereby deriving "color" information concerning the target. Needless to say, the seeker complexity escalates significantly with this latter addition.

The difficulty with these techniques is that they do not appear to provide a sufficiently unique discriminant to permit positive identification and designation of a target. Active signature data is needed to reach a definitive conclusion in this regard; however, analysis from currently available long-wavelength reflectance data makes it doubtful that such a seeker could conclusively discriminate a real target in an array of natural objects, such as large rocks for instance, using only single-color reflectance measurements.

Discrimination of a target among man-made objects provides a worse situation — one which can be quickly made worse by appropriate camouflage paints or surface coatings.

The use of single or multi-color reflectivity measurements should be considered as a corroborating measurement, rather than as a prime discriminant. The combination of this measurement with others in a maximum likelihood estimation matrix may lead to its best usage.



$$D_B = \frac{\alpha R}{\sin \theta_{EL}}$$

Time spread from point C to D

$$\Delta T_{CD} = \frac{2D_B}{c} = \frac{2\alpha R}{c \sin \theta_{EL}}$$

<u>EXAMPLE</u> α = 0.25 mRAD

R = 8

$\theta_{EL} = 10^{\circ}$

$c = 3 \times 10^{8}$ m/sec

$$\Delta T_{CD} = \frac{2 \times .25\ 10^{-3} \times 8 \times 10^{3}}{3 \times 10^{8} \times \sin 10^{\circ}} = 77 \times 10^{-9} \text{ sec}$$

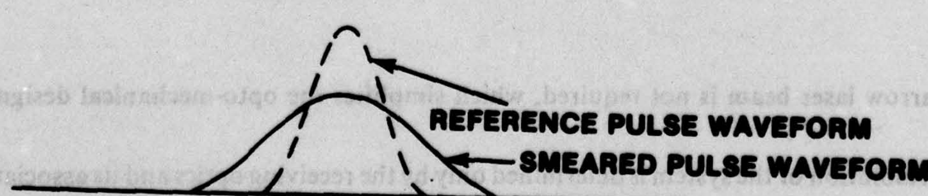


Figure 11. Return signal smear due to viewing angle.

G. MISCELLANY

The possibility of using properties of the coherent seeker to deduce information about target shape has been advanced. Such discrimination can be accomplished by two techniques:

- Pulse-processing methods to assess depth, and
- Pseudo-holographic techniques to assess shape and other related parameters.

The analysis of the return pulse to determine target depth parameters is an attractive method as it is essentially independent of all but the most efficient methods of camouflage. To be effective, however, the system should be capable of a depth resolution better than 1 meter.

Shape discrimination by holographic methods would also appear as an interesting candidate for this missile using an integrated, focal-place mosaic-detector array. Unfortunately, the sensor resolution is still limited by the diffraction of the 10 cm aperture of the seeker, providing about the same angular resolution as could be achieved by a passive IR imaging sensor.

In either case, however, there doesn't appear to be sufficient resolution to provide adequate shape recognition from a range of 3 km; a range of 1 km would bring adequate resolution; however, the latter range is probably too short for adequate decision, lockon, and intercept on the target.

4. CONCEPTUAL MOSAIC ACTIVE LASER SYSTEM

The conceptual system to be discussed here is shown in *Figure 12*. As shown, a laser is used to illuminate a wide area to be searched for potential targets. A mosaic detector array is used to view the illuminated area. This system has a number of advantages. Among these are:

- Scanning within the search field-of-view is eliminated as would be required by a single detector, narrow beam laser system. A gimbal may still be required to point the search FOV, however.
- A narrow laser beam is not required, which simplifies the opto-mechanical design.
- The resolution of the system is determined only by the receiving optics and its associated detector mosaic.

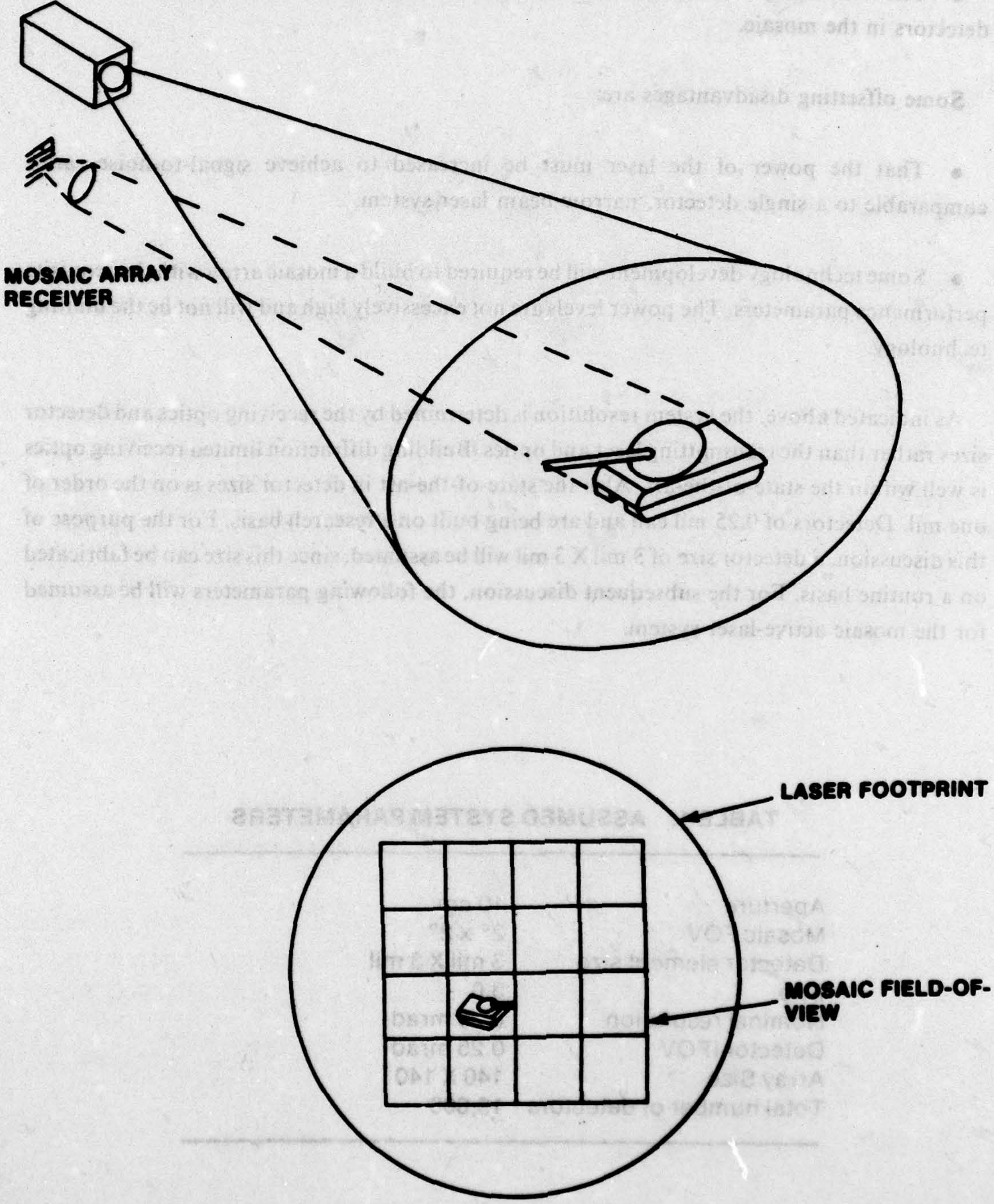


Figure 12. Mosaic active-laser system.

• The total time to search the FOV is reduced by roughly N^2, where N^2 is the number of detectors in the mosaic.

Some offsetting disadvantages are:

• That the power of the laser must be increased to achieve signal-to-noise ratios comparable to a single detector, narrow beam laser system,

• Some technology development will be required to build a mosaic array with the requisite performance parameters. The power levels are not excessively high and will not be the limiting technology.

As indicated above, the system resolution is determined by the receiving optics and detector sizes rather than the transmitting laser and optics. Building diffraction limited receiving optics is well within the state-of-the-art. Also the state-of-the-art in detector sizes is on the order of one mil. Detectors of 0.25 mil can and are being built on a research basis. For the purpose of this discussion, a detector size of 3 mil X 3 mil will be assumed, since this size can be fabricated on a routine basis. For the subsequent discussion, the following parameters will be assumed for the mosaic active-laser system.

TABLE 1. ASSUMED SYSTEM PARAMETERS

Aperture	10 cm
Mosaic FOV	2° x 2°
Detector element size	3 mil X 3 mil
f/no	3.0
Nominal resolution	0.25 mrad
Detector IFOV	0.25 mrad
Array Size	140 X 140
Total number of detectors	19,600

With the system configuration shown in *Figure 12*, a pulse direct detection approach is most appropriate. Although a heterodyne system is conceptually possible, implementing the local oscillator reference over the angular field-of-view for each detector will be very difficult. With a pulse-direct detection system, the potential discrimination techniques are polarization, target contrast, and depth signature. Polarization was discussed in Section 3E. Target contrast is a well established technique and will not be discussed here.

As listed previously in *Table 1*, the total number of detectors required to cover a 2° X 2° FOV with an IFOV of 0.25 milliradians is 19,600. Access to this number of detectors by the conventional approach of individual leads is totally impractical. Currently, a number of techniques are being developed to readout high density mosaic arrays. The two most widely used are Charge Couple Device (CCD) and direct read out or Destructive Readout (DRO) techniques. The CCD approach is inherently capable of higher readout rates due to lower distributed capacitance. Currently, the upper limits on readout rates for CCD's are tens of megahertz for surface channel CCD's and hundreds of megahertz to a few gigahertz for buried channel CCD's. The output sample rate for the conceptual mosaic active-laser system (*Table 1*) is determined by the required bandwidth of each detector and the total number of detectors in the mosaic. Let us assume that we wish to discriminate to a depth differential of 2 feet. This corresponds to a time differential of approximately 4 nanoseconds. The required detector channel bandwidth is roughly the inverse of 4 nanoseconds or 250 megahertz. A minimum sampling criterion requires a sample rate of twice this value or a sample rate of 500 megasamples per second. If we assume a single multiplexed output for the entire mosaic array, the overall output sample rate is

$$\text{Output Sample Rate} = 500 \times 10^{6} \times 19{,}600$$

$$= 9.8 \times 10^{12} \ \frac{\text{samples}}{\text{second}}$$

This is roughly three orders of magnitude faster than the current state-of-the-art. The rate can be reduced by roughly an order of magnitude by permitting submultiplexing of small sections or subarrays. However, it is apparent that some technological improvements will be required to achieve the desired rates. The invention of a new readout technique is not ruled out either.

Another approach to the high data rate problem may be the following. Using a DRO readout technique, the mosaic is read out at a relatively low rate consistent with the limitations

of the DRO. The data is searched for smaller areas where potential targets may exist based strictly on contrasts only. Once these smaller areas are determined, the DRO may be used to access these smaller areas and read them out at a much higher rate. The capabilities of the DRO would have to be determined by further study.

The capabilities of detectors has not been discussed yet. Currently, HgCdTe photodiodes (10.6 μM) have been fabricated which have bandwidth capabilities of up to a few gigahertz. The detectors, therefore, are capable of meeting the 250 megahertz bandwidth requirements. However, these detectors are single element devices and additional work would be required to develop techniques for fabricating high density arrays.

Relative to the mosaic detector arrays, it can be concluded that additional development work is required to achieve higher readout rates as well as to develop techniques for fabricating high density arrays of wide bandwidth detectors. Also, some development work would also be required to build processing electronics to handle the extremely high data rates involved. This is, however, a second order development compared to the detector mosaic and readout technology work.

5. COHERENT SEEKER COST ESTIMATES

Tables 2 and *3* tabulate estimated production costs, in 1,000 unit quantities for pulsed and CW coherent seeker units. The costs are based on a seeker unit only, exclusive of the autopilot and controls. A unit the size of the Maverick seeker is postulated for the costing model. The optical aperture for the system is 10 cm for the combined optical unit, with a separate coaxial 5 cm aperture for the transmitting optics of the CW coherent seeker. For costing purposes, it is presumed that the seeker optical design scans the transmitting beam, in both the pulsed and CW cases, while the receiver field-of-view is stationary, having a diameter equal to the scanned field. Gimbal scanning in a raster pattern accomplishes the acqusition search pattern.

The tables show the costs to be in the \$30K to \$35K region, in 1978 dollars, for both the CW and the pulsed systems. The costs may be expected to escalate to the order of \$60K over a normal ten-year evolutionary cycle due to normal inflation rates.

It is interesting to note the relatively small differential between the CW and the pulsed systems. This differential is so small as to make the costs equal within costing accuracies. This equality appears to be principally due to the relative dominance of the gimbal and servo costs, and to the equality of trade-offs between the use of a dual coaxial system for the CW system versus a common unit for the pulsed system; and the requirement for a local oscillator, Q

TABLE 2. PULSED COHERENT TRACKER COSTS (1,000 UNIT PRODUCTION)

SEEKER ELEMENT	COST ($K)
Gimbal and servo	6
Combined optics	3
Pulsed laser and pump supply	2
Q Switch	1.5
Local Osc Laser	1
Freq Control Loop for Local Osc	0.5
Detector/Preamp	1
Cryogenics	0.75
Range Gate Assy	0.5
Scanner and drive electronics	1
Error processing electronics	2
Discrimination computer	3
IR Dome	2
Final Assy and Test	3
Miscellaneous	5
TOTAL COST	**$32K**

TABLE 3. CW COHERENT TRACKER COSTS (1,000 UNIT PRODUCTION)

SEEKER ELEMENT	COST ($K)
Gimbal	5
Servo	1
Transmitter optics	2
Receiver optics	3
Laser and pump supply	2
Detector and preamp	1
Cryogenics	0.75
Phase lock loop	0.5
Dual optical scanner	2
Error processing electronics	2
Discrimination computer	3
IR Dome	2
Multiple doppler filter	3
Final assy and test	3
Miscellaneous	5
TOTAL COST	**$35K**

switch and a frequency control loop for the pulsed system versus a more complex doppler filter for the CW system. The costs of the electronic components and discrimination computers are treated as being about equal for the two systems within accuracies of this costing effort.

Some cost reductions may be feasible; some increases may occur. Qualitatively, however, the seekers must be more expensive than the current generation of Electro-Optical (EO) seekers, such as Visible EO Maverick. The seekers would be even more complex than imaging IR Maverick as the complexity of the lasers, their pump supplies, the dual optics, and the discrimination electronics of the coherent seeker outweight the multiple element detector array and its signal processing together with the scan converter of IR Maverick. The addition of a video data link to IR Maverick would, however, provide equivalent performance with the coherent systems.

6. CONCLUSIONS AND RECOMMENDATIONS

The following general conclusions were obtained based on the study results.

- Based on signal to noise considerations which determine acquisition range, coherent systems performed better than incoherent systems and pulsed systems are generally better than CW systems.

- Comparing active and passive systems on the basis of SNR, it was determined that the passive 10.6 μM system would generally be superior to the active 10.6 μM system. This would suggest that a hybrid system using passive sensing for initial long range detection and an active system for final discrimination at shorter ranges may be an appropriate overall configuration.

- Of the several potential discriminants examined, it appears that target radial velocity based on doppler measurements and target depth signature are the most promising. Target vibration signature discrimination is another potential candidate. However, there are significant problems due to the masking effects of inherent laser frequency variation noise and the large and variable doppler shift due to the missile forward velocity which would have to be resolved.

The potential for active laser discrimination is clear, based on the study results. However, there remain significant practical issues related to implementations of these techniques. There are several technology development areas which should be studied further. Some of these are:

- Low noise lasers.
- Variable frequency local oscillator lasers for doppler offset compensation.
- Wide bandwidth detector mosaics.
- Associated high speed mosaic readout techniques.
- High speed pulses processing.
- Active seeker opto-mechanical configurations.

DISTRIBUTION

	No. of Copies
Defense Documentation Center Cameron Station Alexandria, Virginia 22314	12
IIT Research Institute ATTN: GACIAC 10 West 35th Street Chicago, Illinois 60616	1
US Army Materiel Systems Analysis Activity ATTN: DRXSY-MP Aberdeen Proving Ground, Maryland 21005	1
DRSMI-LP, Mr. Voigt	1
DRSMI-T (R&D), Dr. Kobler	1
-TBD (R&D)	1
-TI (R&D) (Reference Copy)	3
-TI (R&D) Record Set)	1
-TE (R&D), Mr. Pitman	1
-TEO (R&D), Dr. Curtis	1
	20